INFOTEH-JAHORINA Vol. 16, March 2017.

Precize voltage measurements of multichannel systems on transient temperature conditions

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Abstract—**one of the standard processes in design of integrated circuit is silicon validation. Validation of many specified parameters must be done over the full specified temperature range, which can be from -40°C till 125°C (for industrial and military application), or from -25°C till 85°C (for standard consumer products). In order to detect part to part variations, it is strongly recommended to characterize many devices over temperature range. Specially designed temperature chambers and appropriate hardware are used to provide parallel measurements of various parameters, like voltage, frequency, or current. Special, high temperature and low leakage analog multiplexers are used to multiplex these parameters to one, or couple of measurement devices, usually placed outside of temperature chamber.**

Key words - Integrated circuit; Validation; Temperature chamber; Analog multiplexer

I. INTRODUCTION

Semiconductor device temperature characterization is a very slow process, since temperature chamber is not able to perform fast change of the ambient temperature. In the same time, it is a required process in order to provide required quality of end product [1]. Validation process of one device can last more than couple of days, depends on the temperature resolution and the other setup parameters. If we multiply that time with the number of the devices that needs to be validated, sequential multi-device approach would take too long. That is the main reason to design validation hardware in a way that many devices can be tested and validated in the same time over the same temperature conditions. Just as example, if on one device couple of voltage domains and current consumption of different blocks, or signal shape of different points, needs to be validated/measured, many measurement devices would be needed. That is the main reason to apply multiplexer approach. The same parameter of many tested devices could be measured with only one measurement device.

II. BLOCK DIAGRAM

Simplified block diagram of parallel multiplexed parameter measurements in temperature chamber is shown on Figure 1. Note that all semiconductor devices (DUT) with passive blocks needed for proper function, multiplexer and control blocks are inside of temperature chamber, fully thermally insulated from measurement devices and HOST [2]. HOST provides full software support to the measurement process, acquisition of measurement data and data post-processing.

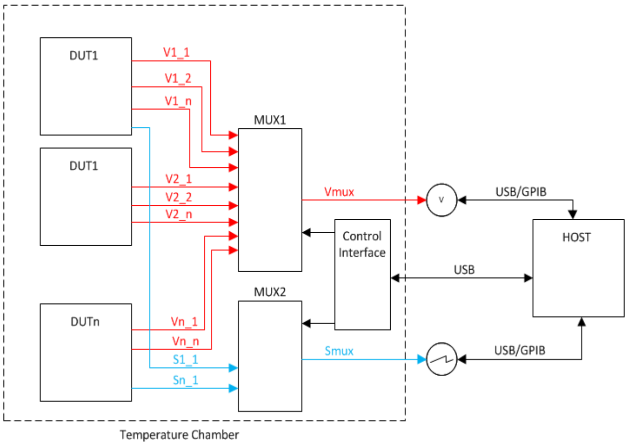

Figure 1: Parallel measurement block diagram

Host should also control temperature chamber using USB interface (depends on temperature chamber interface provided by manufacturer). Note that measurement program should take into account temperature stabilization time. After reaching target temperature, measurement and multiplexing process must not start until temperature overshoots and undershoots are minimized. Time needed for that process depends on the chamber type and it usually takes a couple of minutes.

III. MEASUREMENT ALGORYTHAM AND PROBLEM DESCRIPTION

Measurement of very low internal impedance voltage source is not so demanding process. There are many papers written on this subject and new information, or measurement method of such a voltage source measurement is not the subject of this article. On the other hand, precise measurement of high internal impedance voltage/current source brings more challenges, especially if DUT is placed in socket [3].

A. *Measurement Algorytham*

The following sequential algorytham example can be used in multiplexed measurement, as sown on Figure 2.

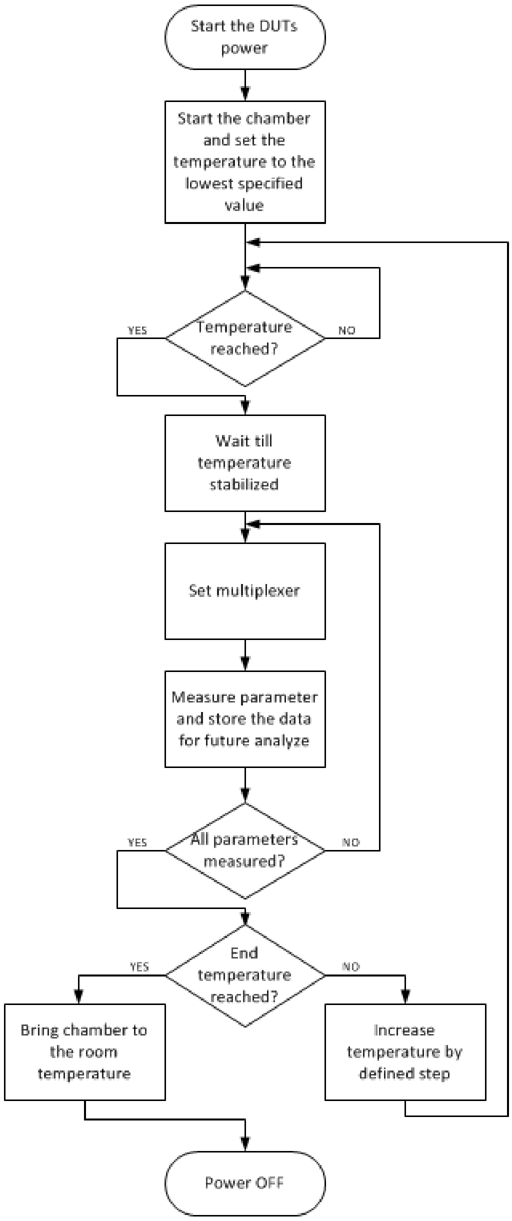

Figure 2: Example of multiplexed parameter measurement in temperature chamber

From the software sideadditional care needs to be taken regarding time delay needed for some blocks operation. For example, after multiplexer switching (which can be treeted as dynamic process), some delay must be introduced before parameter is measured in order to avoid measurement errors due to the dynamic characteristic of measurement circuit.

B. *Multiplexer approach problem description*

Focus of this article is measurement of high internal impedance voltage/current sources under temperature condition. High impedance voltage sources are present in a form of standard reference voltage sources in semiconductor technology, for example.

Multiplexer switch can be built as a relay field with control from the host, but such solution requires higher driving power, much bigger space on the measurement platform, relays are much slower than the modern semiconductor solution and it’s very hard to find relays for high temperatures. All of this makes electromechanical solution not appropriate for temperature measurement multiplexer design. New, low leakage, semiconductor circuits are used as the best solution, taking into account space, speed, temperature and power requirements. One example of Analog multiplexer channel is given on Figure 3 [4].

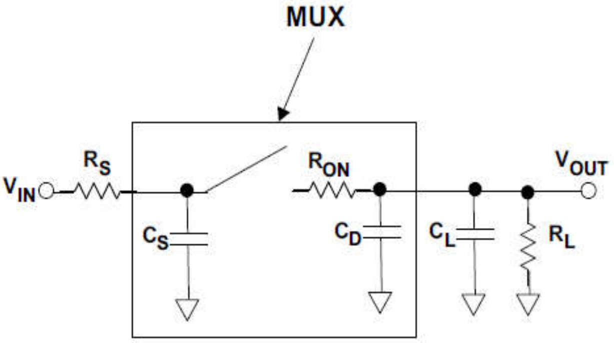

Figure 3: Equivalent circuit of analog multiplexer

What is shown on Figure 3 is channel resistance Rs and Ron, parasitical capacitance to reference potential Cs, Cd and Cl and parasitic resistance to reference potential Rl. Talking about multichannel solution assuming that only low frequency source is multiplexed, block diagram from Figure 1 and schematic from Figure 3 can be modified to Figure 4.

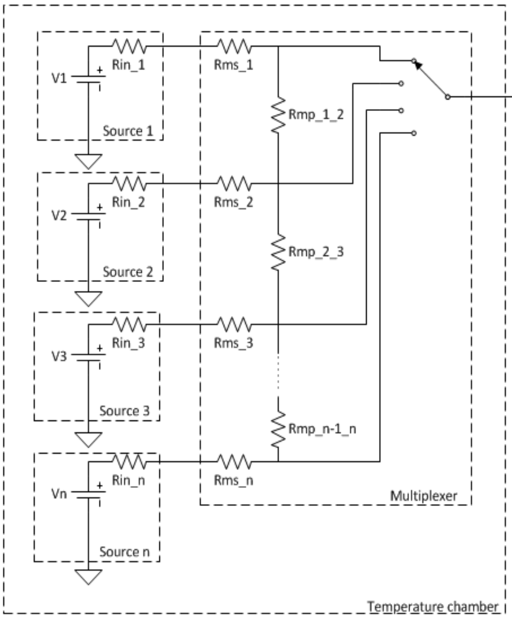

Figure 4: Equivalent multiplexed voltage measurement schematic

Every real voltage source can be presented as ideal voltage source in serial with his own internal equivalent impedance. To make this simple, internal impedance of voltage source is presented just as resistance. For the standard voltage source, like bench power supply, LDO, or switching regulator, this value is very small, in range of mΩ. On the other side, for references in the semiconductor design, internal equivalent resistance can be in the range of couple of hundred kΩ! Reference circuits needs to be measured and characterized with a great precision, which means that every additional block in measurement process can introduce distortion and noise. Looking at the full picture, with multiplexer equivalent schematic and temperature added, as on Figure 4, precise measurement of high impedance voltage source is not an easy task.

Multiplexer equivalent schematic from Figure 4, introduces 3 separate blocks:

- Serial resistance Rms (Ron+Rs on Figure 3), very small value in range of mΩ, which presents channel resistance of MOSFETs used in semiconductor solution.
- Parallel cross-channel resistance Rmp, which is very high value, but highly dependent of temperature and humidity. Note that Rmp with equivalent serial resistance of voltage source creates voltage dividers that can influent measurement accuracy.
- Ideal switch to route selected channel to the measurement device.

What is not introduced on Figure 4 and can influence high impedance source measurement is leakage path to reference potential and to analog multiplexer supply. This leakage path has similar characteristics as cross-channel resistance and basically needs to be taken in consideration. It is good to notice that leakage is also increasing if multiple analog multiplexer's outputs are connected in parallel.

Example of nowadays popular analog multiplexers is Analog Devices ADG1607, differential 8 channel multiplexer [7]. In relatively small package, with single supply, ultralow on channel resistance and high temperature grade it's good solution for low power and sense signals multiplexing.

IV. MEASUREMENT RESULTS AND CORRECTION

As it is stated, humidity and temperature can influent cross conductance value [5], expressed as Rmp, especially at the temperatures between -5°C and +25°C. Reason is decreasing Rmp between input channels which is then overloading input signal. If input signal is very weak voltage source or it's not buffered, overloading effect is drastically visible.

Effect is visible on high impedance sources measurement and temperature transition from low to high, as shown on Figure 5.

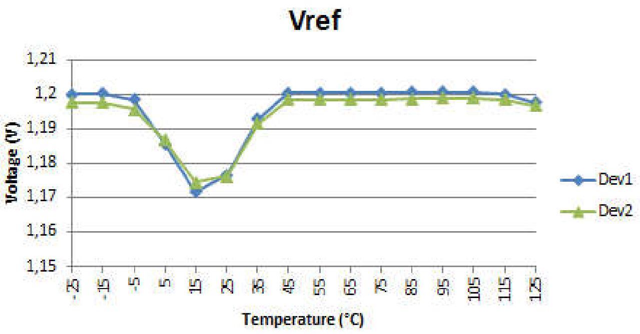

Figure 5: Results of high internal impedance reference voltage measurement over temperature

Performing direct measurement without multiplexer or measuring low internal impedance voltage sources, voltage degradation effect cannot be seen. Unfortunately without multiplexer, measurement of more than 100 parameters requires the same number of indicators, which makes the whole measurement process not practical and expensive. The main task was to understand this effect and to find solution for multiplexer implementation without possible signal degradation.

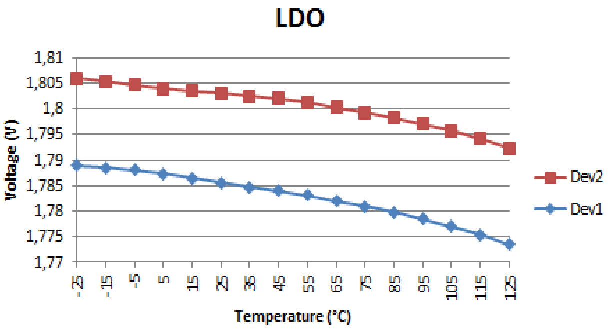

Figure 6: Low internal impedance voltage source results measured through multiplexer

Multiplexer measurement results on low internal impedance source do not recognized signal/voltage degradation in given temperature range, as shown on Figure 6.

The first idea was to place unity gain buffer circuit between voltage source and multiplexer input. Unfortunately there are couples of negative points:

- Each buffer requires well decoupled clean power supply, independent from any other supply used in the measurement process.
- Most of the operational amplifiers that can be used as unity gain buffers require negative supply voltage.
- Each of the buffer introduce offset error to the input signal and this is especially important in semiconductor measurements where sometimes µV precision is required.

- For DC voltage measurements, some of operational amplifiers are not stable. Great care needs to be taken in order to select and test proper amplifier.
- Additional input signal coupling is required for gain and offset stabilization and compensation over full temperature range.

Looking at all of these points, operational amplifiers added as unity gain buffers might not be the perfect and elegant solution. Also, applying solution without full understanding of the problem usually is not the best approach.

Repeating the same measurement, with sweeping the temperature from the highest value down to lowest and using the same measurement devices and software, voltage overloading effect cannot be seen. Even on the high internal impedance sources, measurement curves do not show drop in the temperature range from +25°C to -5°C.

Further investigation involves measurement of humidity inside of the temperature chamber. It has been spotted that measured value of humidity drastically increases in given range. Even if multiplexer with the lowest leakage is chosen, with relative humidity above 80% reduction of cross-channel isolation and also increase of conductivity to reference potential terminal is present.

Implemented solution involves usage of so called dry air pump, which regardless of the temperature process, injects dry air into the temperature chamber space [6]. Dry air pump is shown on Figure 7. Dry air was injected in temperature chamber only from -25°C to +35°C. Dry air pump pressure was 0.1 bar.

Figure 7: Dry air pump

Dry air pump solution require usage of air compressor in addition. Dry air is injecting into the temperature chamber using already built in filters.

Dry air pump solution is implemented and measurements are repeated on high internal impedance voltage sources. Result are shown on Figure 8. Measurements are taken at two points: directly at voltage source (VREF_IN) and at multiplexer output (VREF_OUT). **Curves at both points are the same** which proves that dry air pump solution provides best measurement results and voltage source is not overloaded.

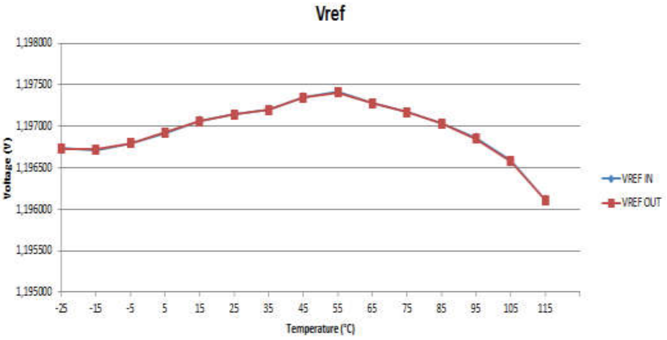

Figure 8: High impedance source measurement at source and after multiplexer with dry air injection

V. CONCLUSION

Using low leakage analog multiplexer [7] in multichannel measurement system is a convenient way of performing measurement tasks without usage of many indicators (voltmeters, oscilloscopes, frequency meters…). Although, analog multiplexer can reduce time and cost of measurement, signal degradation might be present if certain pre-conditions are fulfilled. Example given in previous chapters describes pre-conditions, measurement process and results with signal degradation and provides solution that shows good results.

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